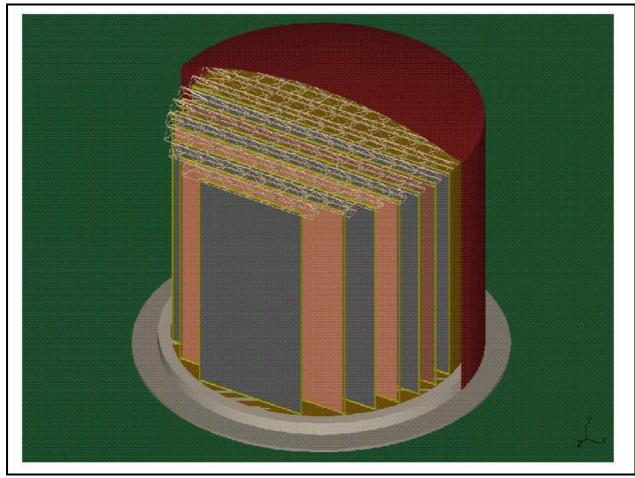


# Particle Physics Division Mechanical Department

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Engineering note num	iber:	Date:	11/30/2004

Experiment	FLARE
Project	Inner tank
Author(s)	Rafael Silva (FNAL)
Reviewer(s)	Bob Wands (FNAL)
Abstract	Preliminary FEA of the FLARE inner tank



Model by Chuck Grimm

## 1. Objective

The goal of this analysis is to indicate if the most desirable basic design ideas for the inner tank are feasible. It seems practical to have the stereo wires supported directly from the vertical cylindrical walls of the tank. It is also much better to have a flat roof that provides the shortest path for the signals from the wires. The electronics at the top of the roof should also be accessible to people. A space frame structure supporting the roof seems to provide a good solution, and that is what is going to be assumed. It would also be best if the vertical cylindrical walls of the tank can support the full load without the need of additional structures or reinforcements.

The inner tank will have at least 3 different loading conditions: full of liquid (for the hydrostatic test), empty and with the wire load (at the end of the assembly), and full of liquid plus the load from the wires.

First, a 1" wall is assumed and a hydrostatic load equivalent to the weight of the argon is applied. From these results, an appropriate wall thickness is devised. Then the wire loads are applied and stresses and buckling checked.

#### 2. Parameters Used

Program: I-DEAS v.9m3 / Simulation.

Analysis: Linear Static, Analysis: Linear Buckling.

Material properties - 9%Ni steel:

density =  $7.32986 \times 10^{-4} \text{ lbf.sec}^2/\text{in}^4$ 

 $\eta = 0.3$ 

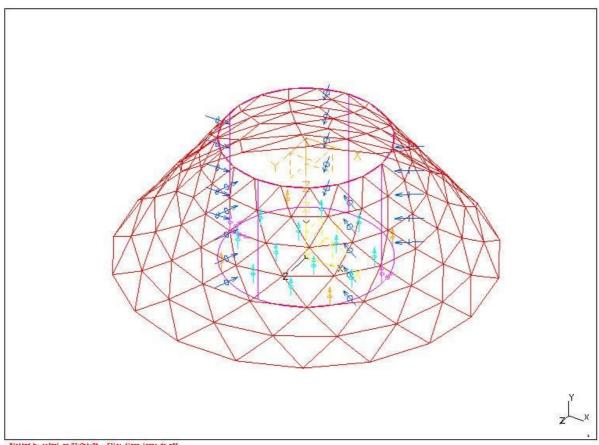
 $= 2.88 \times 10^7 \text{ psi}$ 

Elements: thin shell parabolic quadrilateral, average mesh size about 4'.

## 3. Boundary Conditions

#### 3.1. Hydrostatic load

Bottom of walls is supported vertically only with one point fixed. Load is applied according to data surface defined, as shown below. Gravity is also applied.



#### Piotted by rafael on 27-Oct-04 . File: flore\_inner\_ds.pff

#### 3.2. Wire load

Wire load and gravity are applied. Second, same load but bottom of the tank is fixed and top is restrained in the horizontal directions, free to move vertically.

The space between the wire planes and, consequently, between the space frames is 20 ft. Calculating the load per foot on the longest space frame span at the top of the tank:

Roof: 1/4" plate,  $10.2 \text{ lb/ft}^2 \times 20 \text{ ft} = 204 \text{ lb/ft}$ Cover: 1/8" plate, 5.1 lb/ft<sup>2</sup> x 20 ft = 102 lb/ft

Perlite:  $10 \text{ lb/ft}^3$  x 4 ft thick =  $40 \text{lb/ft}^2$  x 20 ft = 800 lb/ft

Wires: 114,2711b / 130.5 ft = 876 lb/ft

Equipment: 50 lb/ft (guess)

Total: 204+102+800+876+50= 2032 lb/ft

Looking at the Vulcraft catalog for a truss that would work as a space frame (to estimate the weight):

ECONOMICAL JOIST GUIDE
Combined K. VS. LH & DLH Series Load Table

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## ECONOMICAL JOIST GUIDE

Combined K. VS. LH & DLH Series Load Table

4000 Type	Line	Pury	ADMY Magar PERFO	2/25 2001.	AND CASES	e (reus)	east Wilgir	iner Type	à 10 (200	e prop	A COLOR	SIDE SIDE	à 107 L200	- PLP)	VIOLET (IONEC)
1000	LENGT	-		-	LENGT	H /Cor	123	-	LENGT	H (Co	d)	127" LENGTH (Cont.)			200
64DLH12	295	146	20	64CLH 16	387	205	42	64DUH13	27	146	34	720UH 16	354	188	41
6CDLH 13	301	154	34	80CLH 16	407	201	46	GEDUH13	284	166	25	64DUH 16	382	180	46
64DLH 13	310	176	34	720LH 16	435	252	46	64DLH14	316	158	37	72DLH 16	410	221	-
60DLH14	232	166	27	96 H TD 589	460	254	46	GEDUH14	227	17.0	38	64DLH T	430	215	52
64DLH 14	254	180	37	720LH 17	402	267	40	GEDILH15	366	201	42	TABLE T	461	250	93
GEDUH 15	391	228	30	64DLH 17	501	262	92 93	720LH19	366	200	41	64DUH 18	907	243	99
64DUH 15	392 407	194	43 43	BOOLH 18	900 540	280	99	7.2DUH16 68DUH16	433	236 236	45 40	720UH 18	512 540	276	99
ecount 16	428	217	46	64CLH 18	578	206	90	64DLH17	466	237	52	72DUH 10	633	323	6
SEDUH 16	463	266	46	SELLI 18	580	32	60	GEDLH17	480	266	53		. 10 144	2000	137
6CDLH 17	403	247	92	7201.H 10	676	368	6	64DLH18	540	267	50	14	28° LE	NGTH	
720LH 17	505	302	50	SECTH 45	678	271	- 6	660LH18	956	304	60		And the same	0.000000	
64DLH 17	927 956	263	52 50		1000000	SECULIO S		720LH19	654	344	67	64DLH 12	211	109	39
64DLH 18	606	320	50		120° LEI	NGTH						64DLH t3	257	131	34
GEDLH 19	696	301	66	00000000	1000	247		7	124 LEI	NGIH		64DLH 14	202	140	35
	1000		870	600LH 12 640LH 12	232	115	20	64DLH12	224	110	20	68DLH 14 72DLH 14	303	150 166	28
10 p	117" LEI	NETH		60CLH 13	282	130	24	64DLH13	23	111	34	SEDUH 15	337	178	41
- N	to be seen			6401.H 13	291	199	24	6eDLH13	20	164	35	72DLH 16	382	186	41
600UH12	214	124	20	60CLH 14	310	140	35	64DLH14	311	164	37	64DLH 16	376	186	46
64DUH 12	251	142	20	64CLH 14	332	171	35	66DCH14	322	fis.	38	72DLH 16	407	218	£
6COLH 13	206	151	24	SCTH #	337	190	28	SEDUHIS	360	106	42	SADLH T	432	210	92
64DLH 13	305	17.1	24	7201H15	375	211	28	720LH15	363	107	41	GEOTH I	493	238	93.
64DUH14	340	161	27 27	SECTH AS	378	213	40 43	64DLH16 72DLH16	401	203	46 47	64DLH 18	455	248	92
72DLH15	285	222	38	60CTH 16	400	196	46	6EDLH16	427	230	40	EBOUH 18	524	260	60
GEDUH 15	287	224	41	7201.H 16	434	248	45	64DLH17	461	231	52	72DLH 18	536	280	99
64DLH15	400	217	43	980LH 16	448	250	46	SEDUH17	481	262	53	GEOLH 10	601	306	6
6CDLH 16	421	211	46	720LH 17	488	282	40	64DLH18	932	261	50	72DLH 10	628	318	67
64DLH 16	460	242	46	6401.H T	402	255	92	SEDILH18	557	207	60				
GEDUH 16	450	260	46	BOTH L	905	264 250	93.	720LH10	640	330	66	. 3	29° LE	NGTH	
900UH 17 720UH 17	484 901	241	92 90	64CTH 18	501 568	286	99		125 LEI	a servera a		*******	1000	4.40	200
64DLH17	518	275	92		984	321	60	9	125 LEI	N/GI H		EEDLH 13 EEDLH 14	250	146	26
6COLH 18	950	272	50	SCTH &	673	365	6	64DLH12	221	216	20	C2DUH 14	305	163	28
64DLH 18	902	311	50	-	100000		544	64DLH13	260	141	34	72DUH 15	340	182	41
GEDUN 18	500	388	60		121" LEF	NGTH		64DLH14	306	151	37	72DUH 16	403	216	40
720LH 10	687	381	67					GEDUH14	317	17.1	28	GEOUH 17	446	232	93
GEDUH 19	690	384	67	64CTH 45	226	129	20	GEDUH1S	264	101	41	72DUH 17	454	244	93
	and the latest	a eccu	. 17	64CLH 13	286	195	34	7.20LH15	360	104	41	ESCULH 18	516	263	60
	118" LEI	N/GET	L.	ECTH II	326	165	35	64DLH16	304 416	220	46 47	72DUH 18 72DUH 19	532 623	276 313	9
6CDLH12	240	121	20	201H 15	372	207	40	6eDLH16	420	225	40	ALCOHOLD BY	1922	2.00	- 50
64DLH12	247	138	20	BUTH R	375	209	40	64DLH17	464	226	92	199	30" LE	NOTH	
GCDLH 13	291	147	34	720LH 16	430	244	46	GEDUH17	£4	256	53	1	JU LL	Mediti	
6CDLH14	321	156	37	68 DLH 16	444	246	40	64DLH18	923	299	50	GEDLH 13	255	142	36
64DLH14	343	170	37	720LH 17	464	278	40	SEDUH18	510	280	60	GBOUH 14	204	152	20
7200H15	382	218	38	SECTION 1	501	220	93	720UH19	643	233	67	72DLH 14	303	171	20
64DUH 15	224	220	41 43	ESCTH IS	990 570	282	99	- 0	CONT. P.	d desired		720LH 15	345	191	41
GCDLH 16	414	206	46	ECTH 10	667	360	6		126" LEI	MEIH		72DLH 16	401	225	*
7.20XH16	44.1	257	45	-				Carmina	CANA.	464	44	GEDUH TO	451	228 255	5 5
GEDUH 16	466	250	46		122" LEI	NGTH		64DLH12	264	114	20 34	CEDLH 18	508	25	60
7200H17	406	202	90	Electronic management		BITTO NA		64DLH14	201	147	37	720LH 18	928	280	90
64DUH 17	900	266	52	64CTH #5	231	125	20	GEDUH14	312	167	28	GEDUH 10	563	291	6
GEDUN 17	913 919	266	93 90	64CLH 13	261	192	24	7.20LH15	357	191	41	720LH 10	610	328	70
64DUH 18	987	304		BOTH 42	288	171	25	64DLH16	388	193	46	-		or special	- AND EDG
GEDLH 18	994	333	50 60	64CLH 14	321	162	3	7.20LH16	413	225	47	1	31, FE	NGTH	
T20LH19	682	374	67	68CLH 14	332	185	28	64DLH17	446	220	52	1			
GEDIN19	684	377	67	530TH 42	389	204	40	64DLH17	467 915	310 310	53 50	BDIH13	252	138	35
-	NAME OF TAXABLE PARTY.	DUDGI BER		7201.H 16	425	240	46	GEDUH18	540	283	60	BEDIH14	290	148	38 38
	119" LE1	METH		BUTH 19	441	242	40	7.20LH18	514	280	50	72DIH14 68DIH15	322	167	41
	1000	777.00	935	64DLH 17	476	243	92	7.20LH19	606	326	67	72DIH15	342	187	41
6CDLH 12	236	118	29	SETH L	407	275	æ	and the same of th	Name of Street	Williams		72DIH16	395	210	40
64DLH12	243	135	20	640LH 18	540	274	99	7	127 LEI	NGTH		98DIH17	433	222	50
64DLH 13	286	143	34 34	7201.H 19	575 660	311 350	60	(		4		72DIH17	445	250	53
6CDLH 14	316	192	37	SECTH 10	662	383	6	64DLH12	214	111	20	BDIH18	501	251	50
64DLH14	237	174	37		-	75	- 37	64DLH13 64DLH14	260	143	24 27	72DIH18 98DIH19	520 574	263	50 67
GEDUH 14	340	193	38	N	123" LEI	NGTH	177	GEDUH14	306	163	38	72DIH19	600	321	70
7200H15	28	214	28		water build	ALC: NO.		720LH14	300	166	37	0.0000000000000000000000000000000000000	100000		0.0000
SEDUH 15	28.1	217	40	64dh12	228	122	20	SEDUH15	343	182	41				



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131 ft \Rightarrow 4 x 72DLH18, 59lb/ft (each) = 236 lb/ft
118 ft \Rightarrow 4 x 64DLH17, 52lb/ft (each) = 208 lb/ft
87 ft \Rightarrow 3 x 60DLH17, 46lb/ft (each) = 138 lb/ft
```

#### Total:

131 ft  $\Rightarrow$  (236 lb/ft + 2032 lb/ft) x 131 ft = 297,108 lb 118 ft  $\Rightarrow$  (208 lb/ft + 2032 lb/ft) x 118 ft = 264,320 lb 87 ft  $\Rightarrow$  (138 lb/ft + 2032 lb/ft) x 87 ft = 188,790 lb

#### Pulleys:

6582 / side.plane x ~1/2 lb / (pulley + hardware) = 3,300 lb/ side.plane

Not included: cathode planes, field shaping cage.

Total load:

#### Vertical:

Total load applied to one point, at the top of the wall, at the plane location:

131 ft: 148,554 lb, for the analysis  $\Rightarrow$  149,000 lb 118 ft: 132,160 lb, for the analysis  $\Rightarrow$  132,000 lb 87 ft: 94,395 lb, for the analysis  $\Rightarrow$  95,000 lb

Distributed along the wall (all): 18,902 lb + pulleys, for the analysis  $\Rightarrow 22,200$ 

Horizontal, distributed (all): 18,902, for the analysis  $\Rightarrow$  19,000 lb.

#### Total vertical load:

[149,000 lb + 132,000 lb + 95,000 lb + (22,200 lb x 3)] x 4 = 1,770,400 lbWeight of side walls:  $\sim 2,832,182 \text{ lb}$ 

T-4-1: 4 (02 502 11:

Total: 4,602,582 lb

### 4. Allowable Stresses

The criterion adopted in this note is:

Stress intensity (2 x maximum shear stress)

shall be smaller than

23.7 ksi (\*)

(\*) Refer to CB&I documentation (which is based on ASME) – see below.

Welds are full penetration, visually inspected and U.T. tested as to allow 100% efficiency.

Stability: Buckling Load Factor (linear buckling) > 4. Published safety factors for buckling vary according to the application. A safety factor greater than 4 seems consistent with what is recommended by Appendix 3, ASME section II, part D., 1995, item 3-600 (c) (1), p.705.

dge & Iron Company / Products / Refrigerated Storage and Process Systems / Refrigerat... Page 4 of 9

st metals increase in strength with a decrease in temperature. Some, however, such as carbon steel, suffer an almost complete loss of ductility at low temperatures, making them useless for cryogenic vessel construction. Copper, nickel, aluminum and most alloys of these metals exhibit no ductile to brittle transitions and, therefore, are suitable for cryogenic service. Stainless steel of the 18 per cent chrome, 8 per cent nickel classification also exhibits excellent ductility.

Certain minimum requirements have been established by the ASME Code, API Standard 620 and regulatory bodies in the construction of vessels for ultra-low temperatures.

## MATERIALS FOR CRYOGENIC TANKS (THROUGH -450°F)

#### ALLOWABLE STRESS (PSI)

Material	Designation Number	Pressure Storage (ASME)	Flat-Bottom Storage Tanks CB&I Design Methods
Stainless	A240 Type 304	18,750	22,500
Aluminum	AA5052 AA5086 AA5083	6,250 8,700 10,000	7,100 10,500 13,300
5% Nickel 5% Nickel 9% Nickel	A 645 - A553 Class 1 A353	23,700	31,700 31,700 31,700

STRUSS INTENSITY = 23,700 => MAX. SHEAR = 11,850 PSI

Top of Page

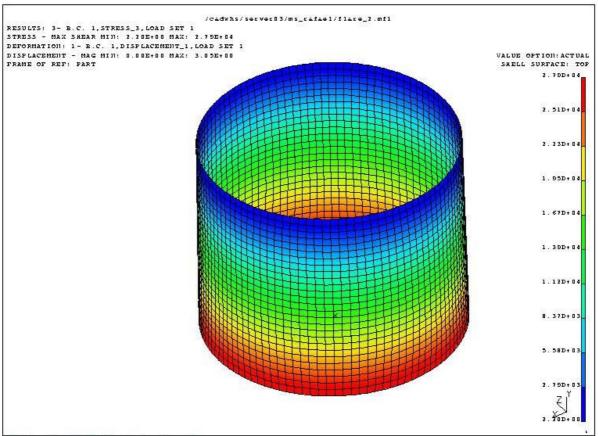
## Tank Shells and Insulation

Refrigerated storage tanks and their insulation systems must be designed to work together to assure optimum performance. Low temperature insulation is required for both spherical and flat bottom cylindrical refrigerated storage tanks.

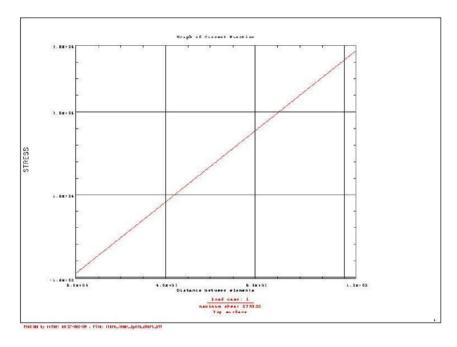
There are three principal types of shell and insulation systems for refrigerated gases: single steel wall (SW), double steel wall (DW), and concrete outer shell with double steel wall interior. Common to both the SW and DW insulation systems is the suspended deck roof insulation system that CB&I introduced in 1966 and load bearing bottom insulation systems. The following portions of this section describe DW, SW, suspended deck roof, and load bearing bottom insulation systems, and the concrete outer shell tanks in more detail.

## 5. Results - hydrostatic load

With 1" thick wall, stress intensity is 55.8 ksi, maximum deflection is 3.1".

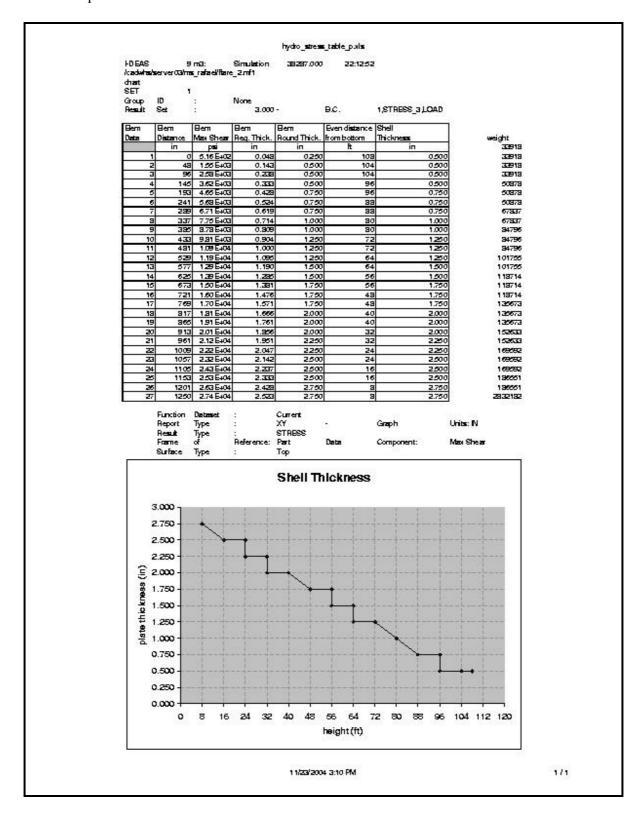


Plotted by rafael on 27-Oct-84 . File: flore\_inner\_hydro\_ne.pff

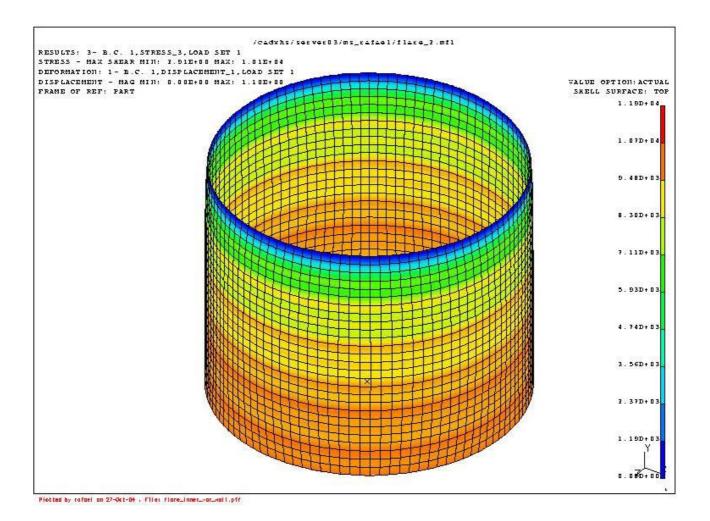


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Scaling from these results, the thickness of the wall was increased in 1/4" increments and 1/2" thickness minimum was adopted.

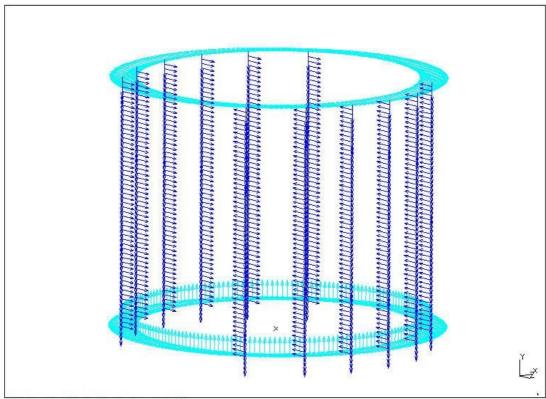


With variable thickness wall, **stress intensity is 20.2 ksi**, which is smaller than 23.7 ksi. Maximum efficiency would show the whole tank in orange but the variation in thickness happens in discreet increments rather than continuously and, at the top, the minimum thickness was set to 1/2". Maximum deflection is 1.1".

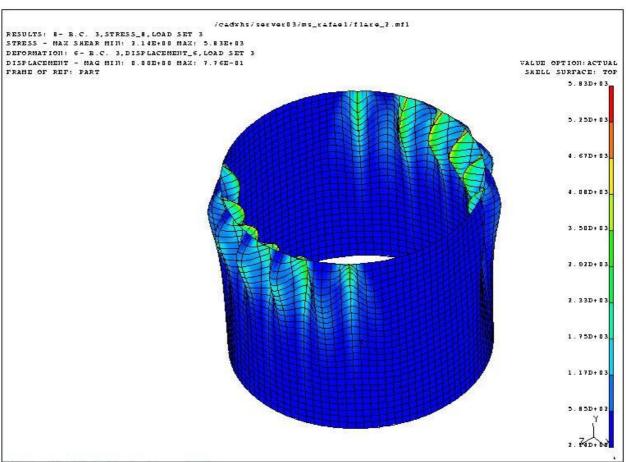


## 6. Results – wire load

Wire load + gravity, bottom of the tank is fixed and top is restrained in the horizontal directions, free to move vertically.



Plotted by rafael on 17-Mos-84 . File: flare\_inner\_var\_br\_fix.pff



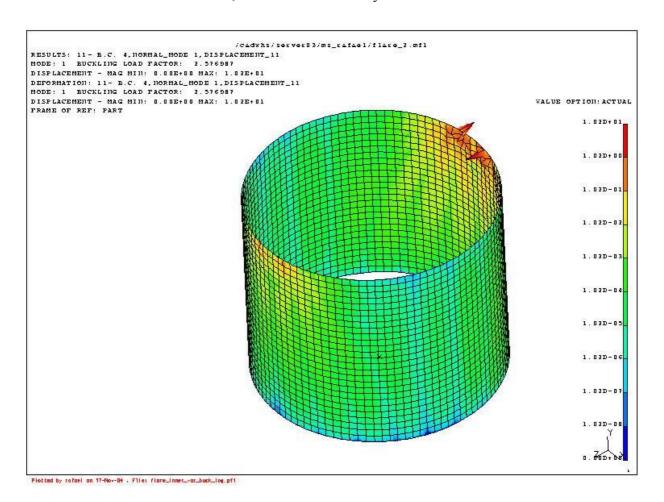
Plotted by rafael on 22-Mos-O4 . File: flore\_inner\_var\_me\_fix.pff

The results are acceptable: **stress intensity is 11.7 ksi**, and maximum deformation is 0.78". That indicates that if the top and bottom are braced appropriately and not allowed to move inwards, the walls would be fine. Hence the space frame needs to provide also bracing for the top and additional bracing is required at the bottom. Further and more detailed analysis is required to determine the bracing needed.

Note that the higher stresses happen at the top, where the plate thickness is 1/2" only.

## 7. Results – stability under wire load

A linear buckling analysis was performed. Same load (wire load + gravity), bottom of the tank is fixed and top is restrained in the horizontal directions, free to move vertically.



**Load Buckling Factor is 2.6,** which is smaller than 4 but happens on 1/2" wall, which can be easily increased.

Then, besides bracing the top and the bottom of the tank, the top part of the wall should have the thickness increased from 1/2".

#### 8. Conclusion

### Having:

- a flat roof,
- stereo wires supported directly from the vertical cylindrical walls of the tank,
- electronics at the top of the roof accessible to people, and
- space frame structure supporting the roof,

seem **feasible**, as long as some requirements are met:

- bracing the top of the tank wall,
- bracing the bottom of the tank wall, and
- increasing thickness of top part of the vertical cylindrical wall from 1/2".

Further and more detailed analysis is required to determine the bracing needed and the appropriate thickness of the wall. The analysis should include all 3 different loading conditions: full of liquid (for the hydrostatic test), empty and with the wire load (at the end of the assembly), and full of liquid plus the load from the wires. It should also include the loads from cathode planes and field shaping cage.